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A Framework for Multidimensional Information Presentation using Virtual Environments

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A variety of Virtual Environment (VE) systems exist today and there are as many terms to them. Synthetic environments, virtual reality (VR), and VEs, to name a few, all refer to a simulation of some operational environment. The gamut of VEs runs anywhere from desktop displays to fully immersive and interactive scenes. What these systems share is the need to capture, process, and present data. Presented effectively, the information can enable a user to make timely and informed decisions.

This paper will provide some examples of current VE technology and present a framework for VE systems. The paper will also address some of the future directions and challenges facing the evolution of VE technology.

1. Current VE Systems

The Office of Naval Research (ONR) sponsors basic research and advanced technology demonstrations in the area of VEs for training. The ONR VE program was founded partially upon the need for affordable, compact, deployable, and reconfigurable training systems. Additionally, the VE program was created to address reductions in manning and increasing training requirements. The training devices demonstrated to date include a pilot trainer for underwater remotely operated vehicles (ROV) and a trainer for submarine and shiphandling.

The ROV trainer is a desktop VE and illustrates at least three important characteristics of VEs. First, performance tests showed that trainees displayed a *positive training transfer* from the desktop training to actual operation. As will be discussed later, the utility of VE systems must be demonstrated in actual operative results. Second, the system, originally built upon an SGI platform, has been transferred to a PC version - an important step in developing portable systems for ease in *deployability*. Last, the desktop system has the potential for use in other types of remote operations and therefore meets the criterion of *reconfigurability*.

Another VE demonstration, the Conning Officer Virtual Environment (COVE) project at the Naval Air Warfare Center Training Systems Division, was designed to train shiphandling skills. This immersive VE incorporates a wide variety of tools including a head-mounted display (HMD), head tracking devices, voice recognition, cognitive modeling of spatial knowledge, and various task analyses.

Future systems will benefit from COVE for a number of reasons. For instance, performance measures, including metrics to compare performance of trainees using HMD versus using regular desktop displays, will be developed. Those types of analyses will help clarify the added value of immersive VE versus traditional training methods. Additionally, to the extent that the technology is available, the COVE project is integrating commercial off-the-shelf products, providing a more *affordable* and *reconfigurable* system than one designed with custom-built components. Finally, the COVE project will provide a platform for other vehicle operations including small craft and amphibious landing craft.

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2. System description

As evident in the VE systems above, the general approach to the developing VE systems is multidisciplinary. The designs include aspects of psychology, computer modeling and simulation, user-interface design, and robotics. They may also include sophisticated hardware such as sensors, tracking devices, HMDs, and large-scale projection screens. The desired complexity of the VE will determine the need for the various components. The following description provides an overview of some of the key components of a VE as seen in Figure 1.

Environmental data capture

Whether the device is used for real-time operations or for mission rehearsal, the data driving these systems are initially captured from the external (or operational) environment. As situations or tasks require, environmental data can be stored and used to generate future scenarios for training, mission rehearsal, or debriefing purposes. Regardless of the intended use, the systems should accurately represent the operational environment (or be able to quickly generate simulations of the external environment). The level of fidelity that the system can present will depend upon the capacity of the sensors, the extraction of relevant information, and the method of data presentation.

System requirements

- Sensors - Systems rely on sensors to detect and capture data from the external world (e.g., radar, sonar, etc.). A misrepresentation of the external environment can lead to the development of a faulty mental model for the user. Subsequently, conclusions and decisions based on faulty information may lead to actions with catastrophic consequences. Therefore, the sensors must accurately capture and represent the details of the operational environment.
- Transcription - The system must have the capability to extract relevant information and discard irrelevant information ("noise") captured from the external environment. There should be built in capabilities to modify the level of granularity at which the data are presented. In some situations providing fine detail may be distracting, whereas an overall picture may be more useful. Those issues need to be addressed through task analyses and comparison studies.
- Presentation – After the data are captured and transcribed appropriately, they must be presented to the user so that the information is useful. Human factor analyses can help determine how to exploit human attention and present information effectively.

The various modes of presentation in VEs can include any combination of the following:

- Visual – The arrangement of visual displays, the content of the display, and the ease in which the user can access specific information can greatly affect how quickly and effectively the user comes to a decision. Weeding through irrelevant information can slow the decision making process and lead to more stressful situations, which in turn can increase the room for error.

- Audio – Studies will need to be conducted to determine in what cases sound enables a decision instead of or in addition to vision. Such issues are important to address because spatial audio, virtual sound, and the integration of virtual with real sound may be among the future components of VEs. A few of the areas researchers will need to examine include whether sound in VEs enhances situational awareness, increases the accuracy of localizing objects, or aids in judging location relative to sound sources (i.e., to aid in navigation).

- Haptics – Haptics refer to the sense of touch derived from contact forces. Haptic interfaces must convey a sense of touch to a user exploring the environment to create a feeling of immersion. Haptics can aid in tasks such as locating and operating manual controls as well as providing pilots with haptic input for signaling their direction or location.

- The integration of visually, aurally, and haptically presented data will create more realistic simulations for fully immersive VEs for training and other tasks. The various applications for multimodal, immersive VEs will be described below (see Section 3).

The human operator
These systems must be designed with the user in mind because certain limitations of human sensory processes will place restrictions on the capacity of the user to obtain useful information from the VE. The system design should also take into account the most effective user response. For example, will a verbal command be a more effective response than a keystroke or push of a button?

Feedback
Whatever the result of the user's action, the system should have the capability to provide feedback about the result. Feedback will enable the user to evaluate and learn from the exercise, whether it is real or training.

Networked systems
The above description applies to a single (VE) unit, however, multiple units will ultimately become networked over systems like local area networks or the internet. Networking VE systems will have an great advantage over traditional training systems in that they can be remotely operated, reach a greater number of trainees, and enable trainees to interact across multiple sites.

3. Applications

Military Training and Operational Tasks - VE systems will continue to be investigated for tasks such as expeditionary warfare in urban settings, mission critical duties, various types of reconnaissance (ground and air), artillery and surface fire support, and close air support (CAS). As mentioned previously, VE trainers will be applied to the piloting of ships, small craft, and amphibious landing craft. Individual VEs in the form of wearable, portable, and wireless devices have potential to facilitate maintenance tasks and tactical decision support.

Information centers – VEs and information displays (e.g., command information centers) will be combined to create multimodal, multifunctional workstations. As evidence of designs for highly effective displays becomes available, the design can be incorporated into VEs and vice versa. To further such a joint venture, a decision support program sponsored by ONR will study through task analyses whether, for example, 3D versus 2D displays are more effective. The program will also use task analyses to determine what cognitive processes, what spatial arrangements, and what aspects of data are critical to decision support.

Commercial - The entertainment industry already uses VEs for a variety of functions, such as immersive video games. VEs are also implemented in telecommunications, information visualization, product design and manufacturing. Similarly, large-scale manufacturers can utilize the technology to prototype airplanes, ships, and other vehicles and test them prior to costly investment in the development of the actual product.

Medicine – VEs have a number of applications for medicine from planing neurosurgery[1] to using virtual patients to teach medical students how to deal with traumatic injuries[2] to teaching anatomy. Additionally, simulators have been created to deepen doctors' understanding of cancer-related fatigue[3]. Finally, modeling pharmaceutical compounds can aid in understanding their mechanism of action and facilitate the development of effective treatments.

Telecommunications - Items such as personal navigation devices or multimodal, wireless phones (3rd generation) will benefit from advancements in VE technology. Similarly, VE technology will benefit from advancement in wireless communications for networking VEs over multiple sites.

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2 Lurie, S. (2000). Innovation and service traditional at University of Michigan Medical School. *JAMA, 283 (7),* 865-866.
3 Vastag, B. & Beidler, N. (1998). Tired out: patients find few easy answers for cancer-related fatigue. *Journal of the National Cancer Institute*, 90, 1591-1594.

4. Challenges

The promoters of VE technology have made several promises about the utility and importance of VEs. Before the developers can deliver on those promises, several technical and scientific issues must be resolved – some of which are outlined and described below.

- Visual - current visual displays are limited in terms of their physical and geometric fields-of-view, depth of focus, visual contrast, resolution, frame rate, weight, and display latency
- Representation of self (avatar) – methods to generate egocentric (a representation as one would normally view their body) or exocentric views need to be developed
- Direct interaction with objects (collision, control, manipulation) – haptic interfaces need to be improved
- Sound – methods to generate spatial audio and virtual sound without enormous expense need further development
- Multidisciplinary approach requires compatibility among system components (computer graphics, behavioral modeling, multimodal interfaces, etc.)
- Faster processors for real-time display of information and multimodal synchronization are needed
- More reliable and higher speed connections and multi-user interfaces are necessary for networking

In the context of training, VE systems must demonstrate efficacy in improving task performance. Further research is needed to determine the extent that 3D, immersive environments create greater situational awareness versus traditional methods. Effective metrics must be in place to evaluate the utility and efficacy of VEs as a teaching tool. Although the development of standard measures will require a concerted effort on the part of program managers and researchers, it is nonetheless achievable.

5. Summary

VEs are dynamic, complex, and powerful tools for information presentation. The capacity of VEs to supply multidimensional representations of data can dramatically change the manner in which those data are examined. The broad spectrum of application domains for VE technology has naturally generated interest from a number of disciplines. As such, one of the greatest challenges to advancing VE technology as whole is creating a collaborative environment where disparate fields can mutually benefit from one another and advance VE technology to its fullest potential.

6. General References

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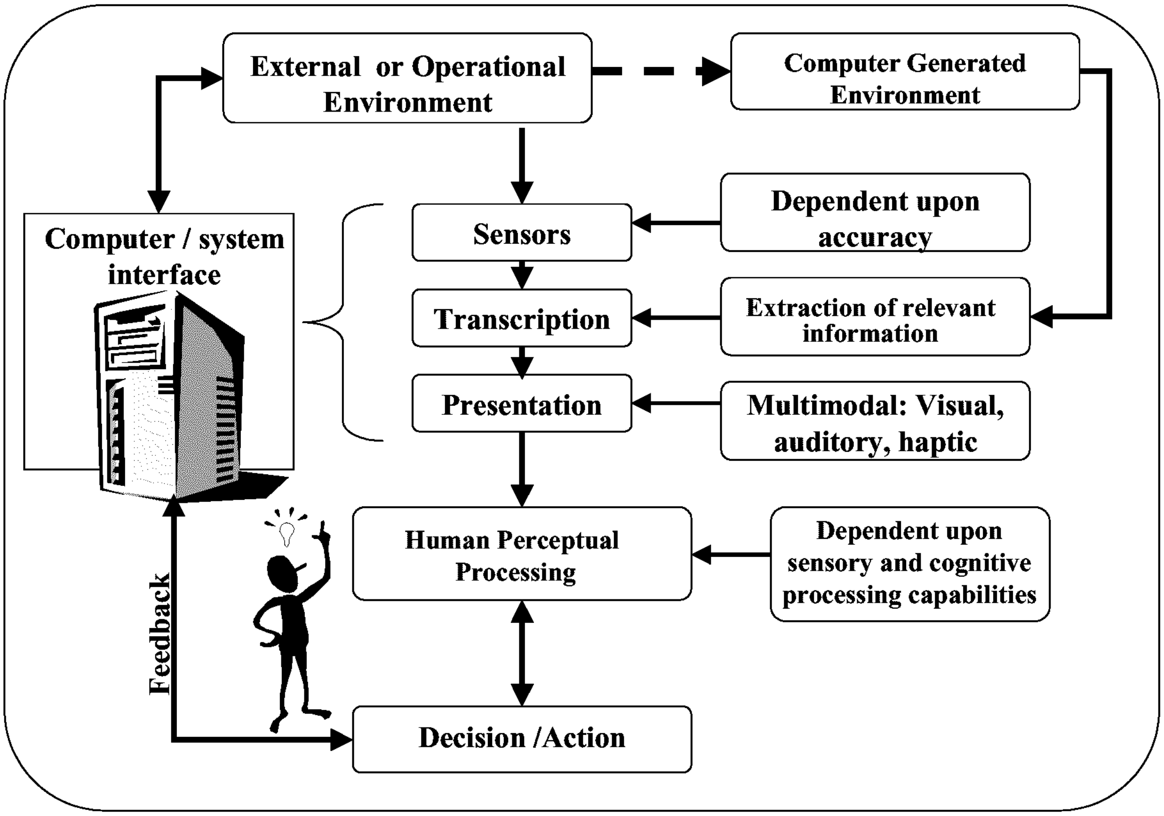

Figure 1. A framework for VE systems. See text for details.

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